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(54) **Title:** PROCESS FOR REPRESENTING AND OPTIMIZING A DOUBLE PROGRESSIVE EYEGLASS LENS

(57) **Summary:** A process is described for representing and optimizing a double progressive eyeglass lens, characterized by the following steps: selection of a suitable coordinate system K2 for representing the rear surface; selection of a suitable grid G for representing, in the K2 [coordinate system], the spline of the rear surface of an initial lens that is to be optimized; definition of a spline via the camber data of the rear surface (rear surface spline); definition of the position of the point of pivoting of the eye; estimation of the principal rays from the point of pivoting of the eye through the initial lens at the grid points of G; calculation of the length of the distance between the points of piercing by the principal ray, which has just been calculated, through the front and rear surfaces (oblique thickness); definition of a spline via the data for the oblique thickness (thickness spline); selection of a set of evaluation positions at which the optical quality is calculated for the target function; suitable selection of certain optical and geometrical standards that are ideally to be achieved at the evaluation locations; definition of the target function in the form of the deviation of the quality of the current eyeglass lens from these ideal values; start of optimization; evaluation at every optimization step of the optical properties at the evaluation locations in the usage position by means of the surface properties, which are to be calculated, and the current principal ray data; terminating optimization when the target function has fallen below a particular value, or after a pre-definable maximum number of optimization steps.

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In order to explain the two-letter codes and other abbreviations, reference is made to the explanatory notes ("Guidance Notes on Codes and Abbreviations") at the beginning of every regular issue of the PCT Gazette.

Process for Representing and Optimizing a
Double Progressive Eyeglass Lens

SPECIFICATION

Technical Area

The invention pertains to a process for producing a double progressive eyeglass lens that comprises, in particular, the representation and optimization of the two surfaces of this eyeglass lens.

Within the framework of the present patent application, the term double progressive eyeglass lens it to be understood to mean an eyeglass lens in which both the front surface and the surface on the side on which the eye is located contribute to increasing the action of the distant vision component and the near vision component.

Prior Art

Progressive eyeglass lenses have been known for a long time. In the case of most of the progressive eyeglass lenses that are known from the patent literature, only one surface is progressive; this means that only one surface contributes to the increase in action from the distant vision component to the near vision component.

In the case of eyeglass lenses in which only one surface contributes to increasing action from the distant vision component to the near vision component, it is known that a particular "series" of progressive "basic curves" is calculated in advance and produced, whereby the second (non-progressive) surface has not yet been machined. The basic curve is termed a surface with a particular surface lens power at the distant vision reference point (in accordance with ISO), and a different (surface) addition depending on the standard. (The (surface) addition in accordance with the ISO standard is the difference between the surface lens power at the distant vision reference point and that at the near vision reference point).

Eyeglass lenses that are finished on one side and that are generally coarsely circular are designated blanks. In these cases, the progressive surface is frequently the front surface.

The action at the so-called "distant vision reference point", which is predefined in accordance with the prescription, is then achieved by means of an appropriately configured second surface: in the case of a progressive front surface, this is therefore achieved via an

appropriate selection of the surface on the side on which the eye is located. In addition, the second surface then produces the astigmatic action that may have been prescribed. Since, in every case, the second surface produces the action that is prescribed in the prescription, the second surface is also designated the prescription surface.

In this connection, it is also known that the prescription surface is individually calculated for the individual usage conditions, such as e.g. pupil separation, forward inclination, cornea/apex separation, etc., with account being taken of the so-called (general) prescription (action at the distant vision reference point, astigmatism and position of the astigmatism axis, together with the addition). It is pointed out explicitly that the above enumeration of the individual usage conditions is not conclusive. On the contrary, reference is [typo] made to the general literature in this connection.

Starting out from an eyeglass lens, which is finished on one side, with one (finished) spherical, aspherical, toric, or atoric surface - generally the front surface - it is also known that the progressive surface is calculated with account being taken of the individual usage conditions and the eyeglass prescription. The progressive surface, which then "provides" not only the increase in action but also the so-called prescription values, is then generally the surface on the side on which the eye is located.

In addition, the proposal was made long ago in the patent literature that eyeglass lenses be provided with two progressive surfaces, i.e. with two surfaces that contribute to the increase in action from the distant vision reference point to the near vision reference point.

The use of eyeglass lenses with two progressive surfaces has the advantage, on the one hand, that the increase in action between the distant vision reference point and the near vision reference point, i.e. the addition, is subdivided over two progressive [typo] surfaces. Since the errors and, in particular, the maximum value of the surface astigmatism, which is present over the surface in question, increase more intensely than linearly with the addition of this surface, smaller image errors are obtained for this reason alone in the case of a progressive eyeglass lens with two progressive surfaces relative to a progressive eyeglass lens with only one progressive surface and the same "total addition".

Moreover, it is possible "to place" the maxima of the disruptive surface astigmatism and other disruptive image errors at different positions in the case of the front surface and the surface on the side on which the eye is located, so that vectorial addition leads to smaller values in total. Furthermore, the image errors of the front surface and the surface on the side on which the eye is located can be compensated, at least in part.

The above statements show that a progressive eyeglass lens with two progressive surfaces also has advantages compared to a progressive eyeglass lens with only one progressive surface when, in the case of a progressive eyeglass lens with only one progressive surface, the second surface is specifically calculated with account being taken of the prescription values and, if applicable, in order to compensate for any image errors of the progressive surface.

On the other hand, many errors can be avoided via the individual calculation of a progressive surface, and thus cases of incompatibility of progressive eyeglass lenses can be avoided.

In the case of progressive lenses with only one progressive surface, it is in fact [possible in accordance with the] prior art to optimize a progressive surface on a given surface, for example a sphere or torus, in such a way that, for example, one minimizes a predefinable target function that defines the optical and geometrical quality.

The individual calculation of at least one progressive surface of a progressive eyeglass lens with two progressive surfaces, which thus contribute to the increase in action, is as yet unknown.

However, this individual calculation would be especially interesting when individual eyeglass lenses with two progressive surfaces are to be produced whose properties are superior to those of individually calculated eyeglass lenses with one progressive surface.

In this case, an interest also exists in rapidly calculating eyeglass lenses with two progressive surfaces, whereby such a calculation is carried out, in particular, in an automatic optimization process.

Disclosure of the Invention

The problem that forms the basis of the invention is to indicate a process for the production of a double progressive eyeglass lens that comprises, in particular, the representation and optimization of the two surfaces of this eyeglass lens, and that permits the individual calculation and production of an eyeglass lens with two progressive surfaces. In particular, the invention is intended to permit the automatic calculation of individual eyeglass lenses with two progressive surfaces.

A solution in accordance with the invention for this problem is indicated in Patent Claim 1. Further developments of the invention are the subject of the dependent claims.

The notion of following the same path as in the case of conventional individually optimized progressive eyeglass lenses would seem to be self-evident for calculating double progressive eyeglass lenses as well. In this case, one would optimize a second surface along with a given progressive surface that generates only a certain portion of the addition of the eyeglass lens, whereby the second surface then provides the remainder of the prescribed increase in lens power together with individual corrections, if applicable, namely astigmatism, position of the astigmatism axis, lens power errors, etc. In extreme cases, the predefined surface could even contribute too much to the addition, and the other surface, which is optimized relative thereto, would then [verb omitted] a degressive surface, i.e. a surface, whereby the addition of the eyeglass lens is reduced in total as a result of the contribution of this surface.

A characteristic feature of this procedure is that one of the two progressive surfaces is kept constant or has been predefined, i.e. its coefficients are not varied during optimization of the other surface. Thus all the degrees of freedom reside in the surface that is varied. This procedure corresponds to the conventional procedure in which blanks are produced on an "in stock" basis.

In accordance with the invention, however, it has become known that significantly better optimization results are achieved only when the front and rear surfaces are optimized at the same time, i.e. the coefficients of the two surfaces are varied simultaneously. In this case, the degrees of freedom of the front and rear surfaces can then become available at the same time.

This is in contrast to the procedure of a technical expert who is active in the area that is being worked in: such a technical expert would naturally stay not only with the conventional procedure in which the blanks are produced, and he would probably also represent the front and rear surfaces in the form of splines on two grids, i.e. the front surface in the form of a spline in the grid of the front surface, and the rear surface in the form of a spline in the grid of the rear surface, i.e. each with its own coordinate system.

However, problems arise during optimization in the usage position, whereby these problems reside in the position of the grid for representing the spline of the front and rear surfaces relative to one another. One of these problems resides at the edge of the area that is to be optimized in each case. The surface is determined by the coefficients within the edge of the spline grid; outside, it is undetermined.

At the beginning of optimization - i.e. in the so-called starting condition - the gird would naturally be selected in such a way that each principal ray, which passes through the point of pivoting of the eye and one of the evaluation points on the rear surface (or on the front surface), pierces the front surface (or the rear surface) within the grid region of the spline. The cambers, surface normals, and surface curvatures then have valid values on the surface in question. During optimization, however, the case can arise in which the cambers and the surface normals of one surface take on certain values such that the primary ray would pierce the other surface outside of the grid, i.e. in a non-valid region. That would lead to non-valid values in the target function, and it would make optimization unnecessarily difficult.

A further problem, which occurs especially in the case of strong actions and in the case where the evaluation grid is fixed, is that, on the rear surface, the divergence of the principal rays between the refracting surfaces can become so large during optimization that entire partial grid regions remain without a piercing point on the front surface, and these therefore remain non-evaluated. Depending on the optimization procedure that is being used, the coefficients that operate there can then be altered in such a way that the local optical properties are distinctly worsened.

General Description of the Invention

In accordance with the invention, a process is indicated in which (preferably) the front surface is represented in the grid of the rear surface. Basically, though it is not preferred, the reverse procedure is possible as well.

Each point on the front surface is described by a corresponding point on the rear surface, whereby this point is above the primary ray and through the point of pivoting of the eye, and by the so-called oblique thickness along this primary ray. If a point is defined on the rear surface via the location vector r_2 (x_2, y_2), then the corresponding point on the front surface r_1 (x_2, y_2) can be calculated as follows

$$\vec{r1}(x_2, y_2) = \vec{r_2}(x_2, y_2) - d(x_2, y_2). \vec{t}(x_2, y_2) \qquad (1)$$

The index 1 pertains to the front surface, whereas the index 2 pertains to the rear surface.

t is the unit vector of the primary ray between the two surfaces in the direction of the light;

D is the so-called oblique thickness and is a scalar magnitude.

The vector -d*t points from the point of piercing by the primary ray through the rear surface to the point of piercing through the front surface.

Thus, in accordance with this definition, the front surface is given or defined there only when a primary ray through the rear surface exists or can be estimated with success. The oblique thickness replaces the function of the front surface. The oblique thickness is represented by splines. In the case of simultaneous optimization, the coefficients of the rear surface are varied together with the coefficients of the oblique thickness.

During optimization, the calculation of the target function takes place at every optimization step, whereby the target function calculates the deviation of the properties of the current lens from ideal notions. Differential geometrical magnitudes, such as surface normals and curvatures at the points of piercing by the principal rays through the surfaces, are needed in order to calculate the properties of the eyeglass lens, and partial derivatives are in turn needed for determining these surfaces.

The calculation of these magnitudes is known from the literature, so that we will not go into this in more detail at this juncture.

In the representation that is used in accordance with the invention, however, calculation of the partial derivatives differs from that of the standard case since the front surface is not represented in its own coordinate system K1, as is usual, by the coordinates of the front surface x_1 and y_1 (approximately via the location vectors r_1 (x_1, y_1) but, rather, in the coordinate system of the rear surface K2 by the coordinates x_2 and y_2:

$$r_1\,(x_2, y_2).$$

The partial derivatives of the front surface in accordance with the coordinates of the rear surface result from the differentiation of (1)

$$\frac{\partial \vec{r}_1}{\partial x_2} = \frac{\partial \vec{r}_2}{\partial x_2} - \frac{\partial d}{\partial x_2}\cdot\vec{t} - d\cdot\frac{\partial \vec{t}}{\partial x_2}$$

$$\frac{\partial \vec{r}_1}{\partial x_2} = \frac{\partial \vec{r}_2}{\partial x_2} - \frac{\partial d}{\partial x_2}\cdot\vec{t} - d\cdot\frac{\partial \vec{t}}{\partial x_2}$$

$$\frac{\partial \vec{r}_1}{\partial x_2} = \frac{\partial \vec{r}_2}{\partial x_2} - \frac{\partial d}{\partial x_2}\cdot\vec{t} - d\cdot\frac{\partial \vec{t}}{\partial x_2}$$

$$\frac{\partial \vec{r}_1}{\partial x_2} = \frac{\partial \vec{r}_2}{\partial x_2} - \frac{\partial d}{\partial x_2}\cdot\vec{t} - d\cdot\frac{\partial \vec{t}}{\partial x_2}$$

$$\frac{\partial \vec{r}_1}{\partial x_2} = \frac{\partial \vec{r}_2}{\partial x_2} - \frac{\partial d}{\partial x_2}\cdot\vec{t} - d\cdot\frac{\partial \vec{t}}{\partial x_2}$$

Thus the derivatives that are needed for calculating the surface properties of the front surface are defined. Differential geometrical magnitudes such as surface normal vectors and principal curvatures then result as in the standard case.

One has different options for achieving the eyeglass in accordance with the process that is indicated here.

One option pertains to subdividing the addition over the front and rear surfaces. Whereas, in accordance with the prior art, the path followed is to provide the front surface with a two-dimensional addition, which exceeds the addition that is in fact necessary and, of necessity, makes the rear surface "degressive", it is preferred, in accordance with this invention, that the two-dimensional additions are either subdivided symmetrically (in the ratio of 50/50 for the front surface to the rear surface) or, at the most, in the ratio of 80/20 or, at least, in the ratio of 20/80. In a proposal in accordance with the prior art (Johnson & Johnson), this ratio would be 130/100, for example.

Another option comprises subdividing the astigmatism over the front and rear surfaces. At least one of the two surfaces has to produce the astigmatic action for a prescribed astigmatism [value]. In the case of the prior art, this is generally the rear surface. In accordance with the invention, the addition and the astigmatism can be subdivided over the front and rear surfaces in any desired manner.

In the case where an astigmatism value amounting to 2 dpt is prescribed, for example, it is conceivable that the front surface be provided with an astigmatism value amounting to 4 dpt which then has to be compensated correspondingly, in the correct axial position, by 2 dpt on the rear surface. In this case, the ratio of the surface astigmatism between the front and rear surfaces is 2. However, surface astigmatism can also be introduced "artificially" in the case of prescriptions for an astigmatism value amounting to 0: e.g. 1.5 dpt on the front surface that is then compensated by 1.5 dpt on the rear surface. The ratio of the surface astigmatism between the front and rear surfaces is 1 in this case.

The advantages of these subdivisions relative to simple progressive eyeglass lenses comprise, on the one hand, a decrease in weight as a result of the reduction of the critical thickness by at least 10% and, on the other hand, a reduction in peripheral astigmatism by up to 30% in the usage position.

PATENT CLAIMS

1. Process for the production of a double progressive eyeglass lens that comprises, in particular, the representation and optimization of the two surfaces of this eyeglass lens,

   characterized by the following steps:

   - selection of a suitable coordinate system K2 for representing the rear surface,
   - selection of a suitable grid G for representing, in the coordinate system K2, the spline of the rear surface of an initial lens that is to be optimized,
   - definition of a spline via the camber data of the rear surface (rear surface spline),
   - definition of the position of the point of pivoting of the eye,
   - estimation of the principal rays from the point of pivoting of the eye through the initial lens to the grid points of G,
   - calculation of the length of the distance between the points of piercing by the principal ray, which has just been calculated, through the front and rear surfaces (oblique thickness),
   - definition of a spline via the data of the oblique thickness (thickness spline),
   - selection of a set of evaluation locations at which the optical quality is calculated for the target function,
   - suitable selection of certain optical and geometrical standards that are ideally to be achieved at the evaluation locations,
   - definition of the target function in the form of the deviation of the quality of the current eyeglass lens from these ideal values,
   - start of optimization,
   - evaluation, at every optimization step, of the optical properties at the evaluation locations in the usage position via the surface properties, which are to be calculated, and the current principal ray data,
   - terminating optimization when the target function has fallen below a particular value, or after a predefinable maximum number of optimization steps, and
   - production of the surface that has been calculated in this way.

2. Process in accordance with Claim 1

   characterized by the feature that the rear surface is represented by a spline in a two-dimensional grid in the coordinate system K2 of the rear surface and by the location vectors $<\rightarrow>r_2(x_2, y_2)$ to the grid points in the K2 [system], whereas the front surface is represented in the same coordinate system K2 by the location vector

   $<\rightarrow>r_1(x_2, y_2) = <\rightarrow>r_2(x_2, y_2) - d(x_2, y_2) \, . \, t(x_2, y_2)$

i.e. through the point on the rear surface and the oblique thickness d, which is represented as a spline, along the principal ray unit vector <→>t.

3. Process in accordance with Claim 1 or 2,
characterized by the feature that the spline coefficients of the rear surface and the spline coefficients of the oblique thickness are optimized simultaneously in one optimization process.

4. Process in accordance with one of the Claims 1 through 3,
characterized by the feature that the two-dimensional grid, on which the spline is represented, can be equidistant or non-equidistant [sic].

5. Process in accordance with one of the Claims 1 through 4,
characterized by the feature that the coordinates are curvilinear coordinates.

6. Process in accordance with one of the Claims 1 through 5,
characterized by the feature that the increase in surface lens power is subdivided over the front and rear surfaces in a ratio that lies between 80/20 and 20/80.

7. Process in accordance with one of the Claims 1 through 6,
characterized by the feature that the surface astigmatism is subdivided between the front and rear surfaces in any desired ratio.

8. Process in accordance with Claim 7,
characterized by the feature that the surface astigmatism ratio between the front and rear surfaces is less than 4.

9. Process in accordance with Claim 7 or 8,
characterized by the feature that the surface astigmatism ratio between the front and rear surfaces is less [than or] equal to 1.

10. Double progressive eyeglass lens in accordance with one of the Claims 1 through 9,
characterized by the feature that it is calculated in accordance with one of the Claims 1 through 9.

11. Eyeglass lens in accordance with Claim 10,
characterized by the feature that the addition and/or the astigmatism is subdivided over the front and/or the rear surface.